

2.2 Newton's law of gravitation

Learning objectives:

- Students should be able to describe and state the knowledge and understanding of:

- Newton's law of gravitation, $F = \frac{GMm}{r^2}$ for the force between two masses
- gravitational field strength $g = \frac{GM}{r^2}$ for a point mass
- gravitational field strength is uniform close to the surface of the Earth and is usually equal to the acceleration of free fall

Additional practice:

10.10 State and explain the factors that affect the gravitational field strength

10.11 Define Newton's law of gravitation and calculate the force

10.12 Calculate forces experienced by a mass in the field of multiple objects

Lesson 2: Newton's law of Gravitation

STARTER: Calculate the force acting on a geostationary satellite of mass 1500 kg, altitude of 35 000 km.

Hint: First find and record Newton's law of gravitation and the equation.

Extension: According to Newton's 3rd law, a pair of forces exists. Identify the location of this force and compare it to the force acting on the satellite.

$6.4 \times 10^6 \text{ m}$

$F = \frac{GMm}{r^2}$

Explain the need for a square-root

Describe how the force changes as the distance is doubled or tripled.

$G = \text{gravitational constant } (6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2})$

$m = \text{mass of smaller or orbiting object}$

$M = \text{mass of larger object}$

$r = \text{separation between the centre of the two objects}$

Ex:

Improve lesson - Starter straight into Newton's law of gravitation field of multiple objects...

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(6) M - State and explain the factors that affect the gravitational field strength
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Using Newton's law of gravitation:

$$F = \frac{GMm}{r^2}$$

$$g = \frac{F}{m}$$

$$g = -\frac{GM}{r^2}$$

Derive an expression for the gravitational field strength by using 'Newton's law of gravitation'

When would you use this equation compared to the equation from last lesson for 'g'?

Ex: Show that the unit is equivalent to ms^{-2}

Answer:

$g = F/m$ is for uniform field.

$g = GM/r^2$ is for a radial field

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Activity: Calculate the gravitational field strength at the surface of the Earth and at a height of 3.2 x 10⁶ m above the surface of the Earth.

Key points: Gravitational field strength is a vector quantity. It is measured in N kg^{-1} or ms^{-2} .

Worked example 1: Use of equation at surface and above surface of the Earth

The Earth can be assumed to be a uniform sphere of radius $6.4 \times 10^6 \text{ m}$ and have a mass of $6.0 \times 10^{24} \text{ kg}$. Calculate the gravitational field strength g :

- on the surface of the Earth
- at a height of $3.2 \times 10^6 \text{ m}$ above the surface of the Earth.

$M = 6.0 \times 10^{24} \text{ kg}$ $r = 6.4 \times 10^6 \text{ m}$

Step 1 Substitute values in equation $g = \frac{GM}{r^2}$

$$g = \frac{6.7 \times 10^{-11} \times 6.0 \times 10^{24}}{(6.4 \times 10^6)^2}$$

$$= 9.81 \text{ N kg}^{-1} \text{ or } \text{ms}^{-2}$$

Step 2 Assume all of the mass is concentrated at the centre. At a height of 3.2×10^6 above the surface, the radius $r = (6.4 + 3.2) \times 10^6 = 9.6 \times 10^6 \text{ m}$

Step 3 Substitute values into equation $g = \frac{GM}{r^2} = \frac{6.7 \times 10^{-11} \times 6.0 \times 10^{24}}{(9.6 \times 10^6)^2}$

$$= 4.36 \text{ N kg}^{-1} \text{ or } \text{ms}^{-2}$$

One misconception of many students is that 'there is no gravity in space' whereas in actual fact the gravitational field strength is only zero when two gravitational field strengths are equal and cancel as in the next example.

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Worked examples Support sheet

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Mount Everest is approximately 9.0 km high. Calculate how much less a mountaineer of mass 100 kg (including backpack) would weigh at its summit, compared to her weight at sea level. Would this difference be measurable with bathroom scales?

Hint

Answer

2.8 N (or 0.3 kg on scales). Measurable with bathroom scales, though hard to achieve accuracy.

	Mass/kg	Radius/km	Distance from Earth/km
Earth	6.0×10^{24}	6400	-
Moon	7.4×10^{22}	1740	3.8×10^5
Sun	2.0×10^{30}	700 000	1.5×10^8

6 Jupiter's mass is 320 times that of the Earth and its radius is 11.2 times the Earth's. The Earth's surface gravitational field strength is 9.81 N kg^{-1} . Calculate the gravitational field strength close to the surface of Jupiter.

Answer

25.0 N kg^{-1}

Plenary 1 and

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